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(54) METHOD AND APPARATUS FOR THE AUTOMATIC REGULATION OF THE AIR RATIO IN COMBUSTION

(71) We, BROWN, BOVERI & CIE AKTIENGESELLSCHAFT, a German Body Corporate, of Kallstadterstrasse 1, Mannheim-Kafertal D6800, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method and apparatus for the automatic regulation of the air ratio in combustion, more particularly combustion in an internal combustion engine, by adjusting the fuel-air mixture intended for combustion in dependence on the measured composition of the exhaust gas.

Regulation of the combustion air ratio of combustion engines to an air coefficient of approximately $\lambda=1$ is known (MTZ Motortechnische Zeitschrift 34 (1973), No. 1 pages 7 to 11). A zirconium dioxide measuring probe is used in this case as a sensor for the exhaust gas air coefficient, a particular property of this probe being that the EMF delivered thereby alters suddenly by a substantial amount when the exhaust gas composition changes from excess oxygen to excess combustible constituents or *vice versa*. No substantial dependence of the EMF on the air coefficient is noted in other regions. This property of the measuring probe is usually not detrimental in known regulation because the air ratio is to be regulated to an air coefficient for combustion of approximately $\lambda=1$.

However, regulation of the air ratio for combustion to air coefficients which differ from a value of approximately $\lambda=1$ i.e. a non-stoichiometric value is desirable in many cases. For example, an air coefficient for combustion of approximately $\lambda=1.25$, i.e. an excess of air, is required for the operation of a four-stroke engine which is to have a small proportion of nitrogen oxides in the exhaust gas, while an air coefficient for combustion of $\lambda<1$, i.e. an air deficiency, must usually be provided for starting the engine. Fuels in firing systems e.g. for boilers are also usually burnt with an excess of air and regulation of the air ratio for combustion to a value of $\lambda>1$ is therefore also required in this case.

The present invention resides in a method for automatically regulating the air ratio of combustion by adjustment of the fuel-air mixture for combustion in dependence on the oxygen content of the exhaust gas, the said oxygen content being measured by effecting afterburning of the exhaust gas and monitoring the afterburned exhaust gas with a solid-electrolyte oxygen measuring sensor which provides an electrical output voltage which changes abruptly when the gas composition changes from excess oxygen to excess combustible constituents or vice versa, the said voltage change being employed for the regulation of the air ratio of combustion, characterised in that to regulate the air ratio of combustion to a non-stoichiometric value, i.e. $\lambda\neq1$, an auxiliary gas stream is admixed with the hot exhaust gas stream intended for measurement, before the latter is afterburned, or a gas constituent of the said exhaust gas stream is extracted before the latter is afterburned, to produce a modified exhaust gas stream which is afterburned and applied to the sensor, so that the air ratio of combustion is adjusted until the afterburned exhaust gas stream has a composition at which the said abrupt change in sensor output occurs.

The invention also resides in apparatus for automatically controlling the fuel/air ratio of a combustion device, comprising a solid electrolyte-oxygen sensor disposed in an exhaust gas path of the device to receive exhaust gas after afterburning thereof, which sensor provides an electrical output voltage which changes abruptly when the monitored exhaust gas composition changes from excess oxygen to excess combustible constituents or vice versa, a control device responsive to the said abrupt change and adapted to adjust the said

fuel/air ratio in response thereto to a value such that the afterburned exhaust gas stream has a composition at which the said abrupt change in sensor output voltage occurs, and means for controllably adding an auxiliary gas to or extracting a constituent from the exhaust gas before afterburning thereof and upstream of the sensor whereby the monitored exhaust gas composition will differ by a predetermined amount from that of the exhaust gas issuing from the combustion device and the said fuel/air ratio will be regulated by said control device at a non-stoichiometric value, i.e. $\lambda \neq 1$.

By means of the invention the range of control can be extended to any desired air ratios outside the particular range of sensitivity of the measuring sensor. The invention can be simply performed in all fields of application and is suitable for most operational conditions.

The exhaust gas stream intended for measurement is constantly maintained at a composition corresponding to a combustion air coefficient of approximately $\lambda=1$ while actual combustion takes place with air ratios different from 1 by virtue of the "offset" produced by introduction of the auxiliary gas or abstraction of part of the exhaust gas. One or more auxiliary gases is supplied or one or more exhaust gas constituents is or are extracted for adjusting the air ratio to the desired value by varying the exhaust gas stream which is intended for measurement. The advantage is that the solid electrolyte-oxygen measuring sensor, which is particularly sensitive at an exhaust gas composition corresponding to a combustion air coefficient approximately $\lambda=1$, can also be utilized for regulation of the fuel-air mixture to values of λ such that $\lambda \neq 1$ in the fuel/air mixture for combustion. Other known regulating methods require separate apparatus for combustion air coefficients of $\lambda<1$ and $\lambda>1$, such apparatus having to detect all gas constituents and having to define the air coefficient by means of a computer. By contrast, the invention is very simple and can be performed with less complexity.

To minimize the amount of auxiliary gas or the quantity of extracted gas, preferably only part of the total exhaust gas stream is utilized for measurement.

To regulate the air ratio of combustion to a constant value, it has been found advantageous if the volumetric ratio between exhaust gas stream which is to be measured and auxiliary gas stream or extracted gas constituents is maintained at a constant value.

On the other hand, if the air ratio of combustion is to be varied in a simple manner it is advantageous to alter the flowrate of the auxiliary exhaust gas stream or of the extracted gas constituents and/or of the exhaust gas stream intended for measurement. Any desired air ratio of combustion can thus be obtained without any interference with the actual regulating system. It is particularly recommended that the exhaust gas stream intended for measurement is maintained at a constant flow rate, and only the flow rate of the auxiliary gas stream or of the extracted gas constituents is altered; adjustment of the air ratio for combustion is thus greatly simplified.

The amount of auxiliary gas supplied to the exhaust gas or the quantity of exhaust gas constituent extracted therefrom can be used as an indication of the desired combustion air ratio which differs from approximately $\lambda=1$ so that the resultant combustion air ratio can be readily preselected in advantageous manner.

An auxiliary gas with a reducing action can be added to the exhaust gas stream for measurement to provide simple adjustment of the combustion air ratio to an air excess ($\lambda>1$), or an oxidizing auxiliary gas can be mixed with the exhaust gas stream for adjustment to a combustion air deficiency. Where appropriate, the mixture of exhaust gas and auxiliary gas is combined on a catalytic afterburner into a corrected exhaust gas stream for measurement.

To simplify the provision of auxiliary gases, it is advantageous if oxygen is used as an oxidizing auxiliary gas and hydrogen is used as a reducing auxiliary gas.

A fuel (for example gasoline) or its cracking products can also be used in place of the reducing auxiliary gas. To this end, the gasoline can be injected into the exhaust gas stream which is to be measured.

Hydrogen and/or oxygen can be generated by electrolytic means and be directly supplied to the exhaust gas stream for measurement, the amount supplied being controlled by the magnitude of the current which is used for electrolysis. Storage and metering of the auxiliary gas are thus simplified.

In one preferred arrangement oxygen is obtained from the ambient air by a solid electrolyte cell and is directly supplied to the exhaust gas stream for measurement, the amount supplied being controlled by the magnitude of the current which is conducted to the solid electrolyte cell. This dispenses with the need for additional gas storage means or gas generators. Furthermore, the solid electrolyte cell electrode on the exhaust gas side can be simultaneously used as a catalytic afterburner. This results in a further simplification.

When making use of the facility of adjusting the air ratio by extracting gas constituents from the exhaust gas stream intended for measurement, the simplest procedure is obtained if oxygen is extracted from the exhaust gas stream to regulate combustion to an excess of air. To this end, a solid electrolyte cell is advantageously used, the amount of oxygen extracted being adjusted by means of the magnitude of the current which is conducted through the solid electrolyte cell.

To minimize overall expenditure, it is advantageous if a common solid electrolyte cell is used for the extraction and supply of oxygen.

It is advantageous if the electrode on the upstream or exhaust gas side of the solid electrolyte-oxygen sensor is used as a catalytic afterburner.

However, it is more advantageous, more particularly in the case of exhaust gases containing lead, if the exhaust gas stream intended for measurement is conducted through a separate catalytic afterburner to the solid electrolyte-oxygen sensor. The risk to the measuring sensor resulting from the lead contained in the exhaust gas is reduced and the sensor service life is increased by separating catalysis and measurement.

In a particularly preferred embodiment, the auxiliary gas supply position and/or the extraction position, the afterburner (if a separate afterburner is provided) and measuring sensor are provided in an exhaust gas branch duct. This provides independence of the run of the exhaust gas duct and the branched exhaust gas stream can be corrected and measured at a position which is situated at a distance from the exhaust gas duct.

However, if a particularly compact embodiment is desired, the exhaust gas branch duct can be a pipe which is open at the ends and is disposed within the exhaust duct, the pipe being in approximate alignment with the exhaust duct and having an internal cross-section which is small in relation to the internal cross-section of the exhaust gas duct.

To maintain a constant exhaust gas stream in the exhaust gas branch duct, it is advantageous if the suction side of exhaust gas delivery means is connected, preferably through a restrictor, to the exhaust gas branch duct downstream of the measuring sensor, the delivery rate of the exhaust gas delivery means being adjustable to any desired constant value. The restrictor will then represent a high resistance to the partial exhaust gas stream so that fluctuations of the pressure and/or flowrate of the exhaust gas stream have no effect in the partial exhaust gas stream and a constant partial exhaust gas stream is obtained in a simple manner.

If the apparatus according to the invention is to be used for exhaust gases the temperature of which is below the minimum temperature of, for example, 300°C, required for catalysis or measurement, it will be advantageous if the exhaust gas duct or the exhaust gas branch duct is provided with heating, more particularly electrical heating, in the region of the measuring sensor and/or of the catalytic afterburner. The minimum temperature required for the reaction on the catalytic afterburner or required for measuring with the measuring sensor can thus be readily and reliably maintained.

Further advantages of the invention are disclosed in the description hereinbelow of embodiments illustrated in the accompanying diagrammatic drawings, in which:

Figure 1 shows a block diagram a regulating device for a four-stroke engine,

Figure 2 shows an axial longitudinal section through part of an exhaust gas branch duct of the engine, in the region of a measuring sensor and a catalytic afterburner,

Figure 3 shows an axial longitudinal section through a part-member of the exhaust gas branch duct with a solid electrolyte cell for the supply of atmospheric oxygen or for the abstraction of oxygen from the exhaust gas, and

Figure 4 shows an oil-fired boiler, in side view, with an exhaust gas duct in which an exhaust gas branch duct is provided, both shown as an axial longitudinal section.

Figure 1 is a block diagram of a regulating device embodying the invention, for a four-stroke engine 6. An exhaust gas branch duct 11 is connected to the exhaust gas duct 13 of the engine 6 upstream of the exhaust gas system 24, which can comprise silencers. A connecting duct 14 extends from an auxiliary gas source 5 to the exhaust gas branch duct. The auxiliary gas source 5 itself is connected through a control conductor to a control apparatus 26. Downstream of the supply position 7 for the auxiliary gas the exhaust gas branch duct extends to a catalytic afterburner 3 and subsequently to a measuring sensor 1. Downstream of the measuring sensor the exhaust gas branch duct extends *via* an adjustable restrictor 19 to the suction side of the exhaust gas delivery means 17 whose delivery side, like the exhaust gas system, opens into the ambient space 25. The measuring sensor 1 is connected through electrical conductors 10 to an amplifier 2 which in turn is connected to a control element 4 which meters the supply of air and/or fuel to the four-stroke engine 6 in

accordance with the amplifier output signal.

In the present embodiment the measuring sensor and the afterburner as well as the supply position for the auxiliary gas are provided in an exhaust gas branch duct. These elements could instead be provided in the exhaust gas duct 13 without affecting the regulating process.

Figure 2 shows a tubular member 20 forming part of the exhaust gas branch duct 11, in axial longitudinal section, and shows the supply position 7 for the auxiliary gas, the afterburner 3 and the measuring sensor 1. The member 20 is provided with a gas mixer in the form of a screen 12 which is situated upstream of the afterburner 3 which is also of tubular construction. A gas mixer screen 12 is also provided between the afterburner 3 and the measuring sensor 1. The measuring sensor 1 itself comprises a catalytically active solid electrolyte-oxygen measuring probe in the form of a tube of zirconium dioxide. The inside and the outside of the said tube are provided with respective porous platinum electrodes 39, 40 and the closed end extends into the exhaust gas branch duct where it is immersed in the exhaust gas stream which is to be measured. The inside of the tube communicates with the external space 25. The output voltage of the sensor changes abruptly when the composition of the exhaust gas stream changes from excess oxygen to excess combustible constituents or *vice versa.* To conduct the signals derived from the electrodes the latter are connected *via* the electric conductors 10 to the amplifier 2. An electric heating system 27 in the form of a heating coil is provided on the outside of the exhaust gas branch duct in the region of the afterburner and of the measuring sensor. The supply position 7 for the auxiliary gas is provided at one end of the member 20 upstream of the afterburner 3 and screen 12. The auxiliary gas source 5 communicates through a connecting duct 14 and a regulating element 16 with the supply position 7. At the other end of the member 20 and downstream of the measuring sensor 1, the exhaust gas branch duct 11 extends *via* the restrictor 19 to the suction side of the exhaust gas delivery means 17 the discharge of which extends into the ambient space 25. The regulating element 16 is adjusted by the control unit 26.

In the present example the afterburner 3 is of tubular construction and incorporated by seamless means into the member 20 of the exhaust gas branch duct. Any other construction of the afterburner is also possible. To increase the mixing action of the screen 12 which is situated upstream of the afterburner it is advantageous if a mixing section is provided between the screen and afterburner, i.e., the distance between the afterburner and the screen 12 should correspond to between one and two times the internal diameter of the exhaust gas branch duct. A screen adapted to function as a mixer might not be required in some circumstances if the mixing section is of suitable length.

Figure 3 shows an axial longitudinal section of a second form of member 20, adapted for the supply or abstraction of oxygen. This embodiment utilizes the second property of a solid electrolyte cell 23, namely that oxygen can permeate through its wall if a current is passed through the wall of the cell by means of the inner and outer porous electrodes 39, 40, for example electrodes constructed of platinum. The direction of oxygen migration depends on the direction of the current. A solid electrolyte cell, for example of zirconium dioxide is incorporated into the member 20. In the present example it is constructed in tubular form and is integral with the part-member 20. The inner porous electrode 39 also forms the catalytic afterburner. It is connected *via* an ammeter 22 to one terminal of a d.c. source. A porous electrode 40, connected *via* an adjustable resistor 28 to the second terminal of the d.c. source, is also mounted on the outer, opposite side of the solid electrolyte cell. The said solid electrolyte cell is provided for simultaneously supplying atmospheric oxygen from the ambient space to the exhaust gas stream or for the abstraction of oxygen from the exhaust gas stream. In addition the inner electrode of the said cell is also used as catalytic afterburner.

The measuring sensor 1, which in the present case is also integral with the exhaust gas branch duct 11, is disposed downstream of the fixed electrolyte cell 23. The inner and outer electrodes are connected *via* the electrical conductors 10 to the amplifier 2 which acts on the regulating element 4. Downstream of the measuring sensor the exhaust gas branch duct extends *via* the adjustable restrictor 19 to the suction side of the exhaust gas delivery means 17 the discharge of which extends into the ambient space 25. The measuring sensor 1 and the solid electrolyte cell 23 are provided with an electric heating system 27, for example in the form of a heating coil.

Figure 4 shows a boiler 36 in side view. It is provided with an oil burner 38. A short tube 15, opens at the ends and situated in the exhaust gas duct 13, functions an exhaust gas branch duct 11 and has a diameter which is small in relation to that of the exhaust gas duct. The said tube is in

alignment with the exhaust gas duct, is spaced therefrom and is provided near the exhaust gas exit from the boiler. The tube 14 is supported by the exhaust gas duct 13 by means of a stub pipe 41 which incorporates part of the measuring transducer 1 and thus forms a screen for the measuring sensor with respect to the exhaust gas stream 18 where it penetrates through the exhaust gas pipe 13. The supply position 7 for the auxiliary gas is an orifice upstream of the measuring sensor, which projects into the tube 15, the connecting duct 14 of the auxiliary gas source 5 being connected to the said orifice.

The measuring sensor 1 in this case has approximately the same construction and is arranged like the measuring probe of Figure 2. A separate afterburner is however not provided because the solid electrolyte-oxygen measuring sensor electrode on the exhaust gas side is also used as catalytic afterburner. The measuring sensor is connected in conventional manner to an amplifier 2 which in turn is connected by electrical conductors 34 to the burner 38 for regulating the air-fuel mixture. If necessary, an electric heating system 27 can be provided in the region of the measuring sensor 1.

In the present case, the auxiliary gas is generated in an electrolysis cell 21. This comprises a tube, bent into a U-shape and filled with an aqueous electrolyte 29. Electrodes 30, which are connected through an ammeter 22 or a variable resistor 28 to the terminals of a d.c. source, are immersed in the said electrolyte. Each of the gas spaces of the two members of the electrolyte cell 21 is connected through a pipeline to a three-way valve 31 the third tapping of which is connected to the duct 14. Appropriate adjustment of the three-way valve 31 permits optional connection of the supply position 7 to the side of the electrolysis cell which produces oxygen or hydrogen respectively.

The operation of the device and the procedure of the method will be explained by reference to Figure 1.

If the air ratio with which the four-stroke engine 6 is operated is to be regulated to a combustion air coefficient different from 1 metered auxiliary gas from the auxiliary gas source 5 is mixed at the supply position 7 with the exhaust gas stream or the branched-off part of the exhaust gas stream. The auxiliary/exhaust gas mixture is then conducted to the afterburner 3 where the constituents react with each other so that a modified, exhaust gas stream is produced. This is drawn off by the exhaust gas delivery means 17 *via* the measuring sensor 1 and the restrictor 19 and is exhausted. The exhaust gas delivery means produces a uniform flow of the exhaust gas which is to be measured. This is assisted by the adjustable restrictor 19 which results in a high pressure drop so that pressure and/or flowrate changes in the exhaust gas duct 13 have little or no effect on the exhaust gas quantity which is branched off from the exhaust gas delivery means. The signal measured by the measuring sensor is transmitted *via* the electrical conductors 10 to the amplifier 2 which acts on the regulating element 4 to adjust the proportions of fuel and air of the infed fuel-air mixture. The air and fuel can be mixed outside the engine, for example in a carburettor, or within the cylinder of the engine, for example by air suction and fuel injection.

To obtain regulation to a combustion air coefficient $\lambda>1$, the exhaust gas stream is mixed, for example with hydrogen. The hydrogen reacts in the catalytic afterburner 3 with the exhaust gas to produce a modified exhaust gas stream having an oxygen deficiency at the sensor. The measuring sensor records the deviation very rapidly by an abrupt change of output voltage which, through the amplifier 2 and the regulating element 4, causes an increase in the proportion of air in the fuel/air mixture. This proportion is maintained until the air proportion in the exhaust gas is so large that reaction of the recess air in the measured exhaust gas with the added hydrogen in the afterburner 3 produces at the sensor an exhaust gas stream with no oxygen deficiency (or excess) and this is then maintained by the regulator. Due to the increased supply of air, combustion will therefore take place with an excess of air. The amount of hydrogen supplied per unit time defines the amount of combustion air excess and the quantities of hydrogen can be directly associated with combustion air coefficients.

Oxygen is supplied as the auxiliary gas if the engine is to be operated with a combustion air deficiency, i.e. with a combustion air coefficient $\lambda<1$. The addition of oxygen to the exhaust gas causes the sensor to detect an oxygen surplus in the exhaust gas and the sensor therefore causes the regulating element 4 to restrict the supply of air and/or increase the supply of fuel to the engine. Combustion in the engine then takes place with an air deficiency and the exhaust gas will contain unburnt combustible constituents. Regulation continues until the amount of auxiliary oxygen supplied is compensated by the unspent fuel constituents in the exhaust gas stream.

The air ratio of combustion can be set to any desired value solely by supplying a corresponding auxiliary gas and regulating

the combustion air coefficient to maintain the exhaust gas stream at a composition corresponding to stoichiometric combustion.

In the case of a four-stroke engine, metering of the auxiliary gas is advantageously controlled *via* the engine temperature and/or its rotational speed and/or other factors, through the control apparatus 26.

In the apparatus according to Figure 2, the auxiliary gas is added for mixing at the supply position 7 in the member 20 of the exhaust gas branch duct 11. To improve mixing, a gas mixer in the form of screen 12 is disposed downstream of position 7 so that a uniform exhaust gas-auxiliary gas mixture enters the catalytic afterburner 3. The auxiliary gas reacts therein with the exhaust gas constituents, is again mixed by the second screen 12, disposed downstream, and is then conducted to the measuring sensor 1. The electric heating system 27, which is set into operation if the exhaust gas temperature is less than 300°C, is also provided since a specific minimum temperature is necessary for measurement and for reaction on the catalytic afterburner. Adjustment to different air ratios is performed in the manner described hereinabove.

Instead of supplying hydrogen to the exhaust gas stream, it is also possible to extract oxygen, if this is present, so as to produce an air deficiency in the measured exhaust gas stream and thereby to cause the regulating system to supply an increased amount of air for combustion. Figure 3 shows a device suitable for extracting or supplying oxygen.

A d.c. current is conducted in the appropriate direction *via* the electrodes 39, 40 of the solid electrolyte cell if oxygen is to be abstracted from the exhaust gas stream that is to be measured. The consequence is that oxygen migrates through the wall from the interior of the solid electrolyte cell 23 to the exterior 25 and the air coefficient of the exhaust gas stream for measurement is reduced. The measuring sensor 1 detects this state and compensates for it in the manner described hereinafter by increasing the supply of air for combustion.

For operation of the engine with an oxygen deficiency, oxygen is supplied to the stream of exhaust gas that is to be measured, by reversing the direction of the electric current which flows through the wall of the solid electrolyte cell. Oxygen is then abstracted from the ambient atmosphere and is supplied to the exhaust gas stream that is to be measured. An excess of oxygen is thus produced at the sensor and is recorded by the sensor and is compensated by restricting the supply of air for combustion until the exhaust gas stream measured by the sensor no longer has an oxygen excess. The quantity of oxygen which is abstracted or supplied in unit time can be used as a measure of the air coefficient.

The solid electrolyte cell 23 acts as a catalytic afterburner and senses the composition of the afterburner exhaust gas stream. A heating system 27 is put into operation when necessary.

In the arrangement shown in Figure 4, the short tube 15, open at the ends, is mounted in the exhaust gas duct 13 to function as a branch exhaust gas duct. Part of the exhaust gas 18 which leaves the boiler flows through the tube 15 and past the sensor 1.

The auxiliary gas (oxygen or hydrogen) is admixed at the supply position 7 immediately downstream of inlet to the tube 15. The auxiliary gas passes *via* a mixing section 33 to the measuring sensor 1. No separate afterburner is interposed since the measuring sensor electrode on the exhaust gas side acts as a catalytic afterburner before the exhaust gas composition is sensed. The measured result is supplied *via* conductors to the amplifier 2 which is connected through an electric conductor 34 to the oil burner 38 to provide regulation of the fuel-air mixture of the latter. A reducing auxiliary gas, in the present example hydrogen, is added to the exhaust gas stream that is being measured so that a modified exhaust gas stream with an air deficiency is produced, since boiler firing systems are usually operated with an excess of air. The resulting increased supply of air for the combustion process increases the oxygen content of the exhaust gas 18 to the extent that the afterburner exhaust gas mixture monitored by the measuring sensor 1 has no air deficiency, which condition is maintained by the regulating system so that combustion is performed with an excess of air.

The hydrogen — and where necessary also the oxygen — in the embodiment of Figure 4 is produced in an electrolysis cell 21. To this end, a suitable aqueous electrolyte is decomposed and the resultant hydrogen is mixed with the auxiliary gas. Metering of the auxiliary gas can be adjusted by the magnitude of the current used for electrolysis. The adjustable resistor 28 and the ammeter 22 are provided to this end. Any kind of auxiliary gas generator or store can be used, for example solid gas-absorbing materials or compressed gas stores to function as auxiliary gas source. Furthermore, the kind of auxiliary gas employed is of no consequence, it must merely have a reducing action in one case and an oxidising action in the other case. A

fuel-air mixture can therefore also be used as a reducing auxiliary gas.

It is evident that the regulating device according to Figure 4 can also be employed in conjunction with four-stroke engines, and the embodiments illustrated in Figures 2 and 3 can also be applied to boilers.

WHAT WE CLAIM IS:—

1. A method for automatically regulating the air ratio of combustion by adjustment of the fuel-air mixture for combustion in dependence on the oxygen content of the exhaust gas, the said oxygen content being measured by effecting afterburning of the exhaust gas and monitoring the afterburned exhaust gas with a solid-electrolyte oxygen measuring sensor which provides an electrical output voltage which changes abruptly when the monitored gas composition changes from excess oxygen to excess combustible constituents or vice versa the said voltage change being employed for the regulation of the air ratio of combustion, characterised in that to regulate the air ratio of combustion to a non-stoichiometric value, i.e. $\lambda \neq 1$, an auxiliary gas stream is admixed with the hot exhaust gas stream intended for measurement, before the latter is afterburned, or a gas constituent of the said exhaust gas stream is extracted before the latter is afterburned, to produce a modified exhaust gas stream which is afterburned and applied to the sensor, so that the air ratio of combustion is adjusted until the afterburned exhaust gas stream has a composition at which the said abrupt change in sensor output occurs.

2. A method according to Claim 1, characterised in that only part of the total exhaust gas stream is utilized for measurement.

3. A method according to Claim 1 or 2, for regulating the air ratio of combustion to a constant value, characterised in that the volumetric ratio of the exhaust gas stream for measurement to the auxiliary gas stream or to the abstracted gas constituent is maintained at a constant value.

4. A method according to Claim 1 or 2, characterised in that the flowrate of the auxiliary gas stream or of the abstracted gas constituent and/or of the exhaust gas stream intended for measurement is altered for varying the air ratio of combustion to a different value of λ.

5. A method according to Claim 3 or 4, characterised in that the exhaust gas stream intended for measurement is maintained at a constant flow rate.

6. A method according to any of Claims 1 to 5, characterised in that the amount of auxiliary gas supplied or the quantity of exhaust gas constituent abstracted is utilized as an indication of the desired combustion air ratio.

7. A method in accordance with any of Claims 1 to 6, characterised in that an auxiliary gas with a reducing action is supplied to the exhaust gas stream for measurement, for the purpose of adjusting the combustion air ratio to an air excess.

8. A method as claimed in any of Claims 1 to 6 in which for adjusting the combustion air ratio to an air deficiency an oxidizing auxiliary gas is mixed with the exhaust gas to be measured.

9. A method according to Claim 8, characterised in that the oxidizing auxiliary gas is oxygen.

10. A method according to Claim 7, characterised in that the reducing auxiliary gas is hydrogen.

11. A method according to Claim 7, characterised in that to adjust the combustion air ratio to an air excess a fuel or its cracking products are mixed with the exhaust gas to be measured.

12. A method according to Claim 9 or 10, characterised in that the hydrogen or oxygen is produced electrolytically and is supplied directly to the exhaust gas stream for measurement, and the amount supplied is controlled by the magnitude of the current which is utilized for electrolysis.

13. A method according to Claim 9, characterised in that the oxygen is obtained from the ambient air by means of a solid electrolyte cell and is supplied directly to the exhaust gas stream for measurement, and the amount supplied is controlled by the magnitude of the current that is conducted to the solid electrolyte cell.

14. A method according to Claim 13, characterised in that the electrode on the upstream side of the solid electrolyte cell is also utilized as a catalytic afterburner for the exhaust gas.

15. A method according to any of Claims 1 to 6, characterised in that oxygen is extracted from the exhaust gas stream intended for measurement for the purpose of adjusting the air ratio of combustion to an air excess.

16. A method according to Claim 15, characterised in that the oxygen is extracted by means of a solid electrolyte cell, the extracted quantity being adjusted by means of the magnitude of the current which is conducted through the solid electrolyte cell.

17. A method according to Claim 16 when dependent on Claim 13 or 14, characterised in that a common solid electrolyte cell is utilized for the extraction and for the supply of oxygen.

18. A method according to any of Claims 1 to 12, characterised in that the solid electrolyte-oxygen measuring sensor

electrode on the upstream side is utilized as a catalytic afterburner for the exhaust gas.

19. A method according to any of Claims 1 to 12, characterised in that the exhaust gas stream intended for measurement is conducted over a separate catalytic afterburner to the solid electrolyte-oxygen measuring sensor.

20. A method of controlling the fuel/air ratio in combustion, as claimed in Claim 1 and substantially as herein described.

21. Apparatus for automatically controlling the fuel/air ratio of a combustion device, comprising a solid electrolyte-oxygen sensor disposed in an exhaust gas path of the device to receive exhaust gas after afterburning thereof, which sensor provides an electrical output voltage which changes abruptly when the monitored exhaust gas composition changes from excess oxygen to excess combustible constituents or vice versa, a control device responsive to the said abrupt change and adapted to adjust the said fuel/air ratio in response thereto to a value such that the afterburned exhaust gas stream has a composition at which the said abrupt change in sensor output voltage occurs, and means for controllably adding an auxiliary gas to or extracting a constituent from the exhaust gas before afterburning thereof and upstream of the sensor whereby the monitored exhaust gas composition will differ by a predetermined amount from that of the exhaust gas issuing from the combustion device and the said fuel/air ratio will be regulated by said control device at a non-stoichiometric value i.e. $\lambda \neq 1$.

22. Apparatus according to Claim 21 comprising a regulator for adjusting the fuel/air ratio for combustion, the regulator being connected to the sensor.

23. Apparatus according to Claim 21 or 22, characterised in that the addition and/or extraction position and the measuring sensor are situated in an exhaust gas branch duct in which in operation the afterburning takes place.

24. Apparatus according to Claim 23, characterised in that the exhaust gas branch duct is a tube which is open at the ends and is disposed within an exhaust gas duct, the tube being approximately in alignment with the exhaust gas duct and having an internal cross-section which is small relative to the internal cross-section of the exhaust gas duct.

25. Apparatus according to Claim 23 or 24, characterised in that the suction side of exhaust gas delivery means is connected to the exhaust gas branch duct downstream of the measuring sensor, the delivery rate of the exhaust gas delivery means being adjustable to any desired constant value.

26. Apparatus according to any of Claims 21 to 25, including for the controllable addition of the auxiliary gas stream at least one auxiliary gas source, a connecting duct extending from the said source to the exhaust gas path, and an intermediately disposed regulating element.

27. Apparatus according to any of Claims 21 to 26, including as a source of the auxiliary gas an electrolysis cell or a solid gas-absorber.

28. Apparatus according to any of Claims 21 to 26, comprising for the controllable addition or extraction of oxygen a solid electrolyte cell one side wall of which adjoins the exhaust gas stream for measurement and the other side of which adjoins an ambient space, the electric current flowing through the wall of the solid electrolyte cell being adjustable for metering the quantity of oxygen supplied to provide the desired fuel/air ratio.

29. Apparatus according to Claim 28, characterised in that the solid electrolyte cell comprises at least part of an exhaust gas duct or said exhaust gas branch duct.

30. Apparatus according to any of Claims 21 to 29 including a separater afterburner in the exhaust gas path upstream of the oxygen measuring sensor.

31. Apparatus according to any of Claims 21 to 30, characterised in that the exhaust gas path or the said exhaust gas branch duct in the region of the measuring sensor and/or of the separater afterburner if a separate afterburner is provided, and/or the measuring sensor or afterburner itself, is or are provided with a heating system.

32. Apparatus according to any of Claims 21 to 31 including a catalytic afterburner.

33. Apparatus according to any of Claims 21 to 29 or to Claim 31 when dependent thereon, in which a component of the sensor constitutes a catalytic afterburner for the afterburning of the exhaust gas.

34. Combustion control apparatus substantially as herein described with reference to Figure 1, 2, 3 or 4 of the accompanying drawings.

MARKS & CLERK.

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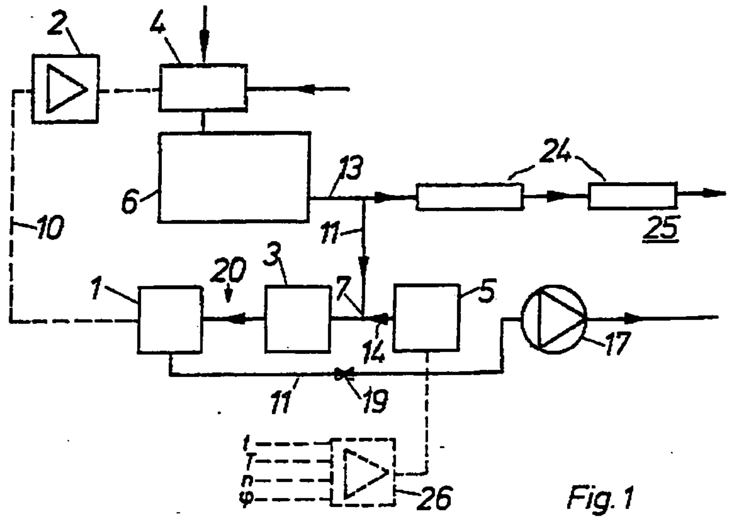

Fig. 1

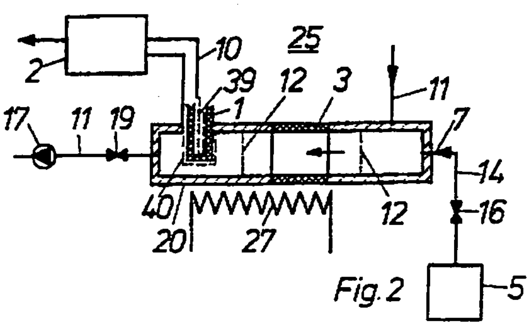

Fig. 2

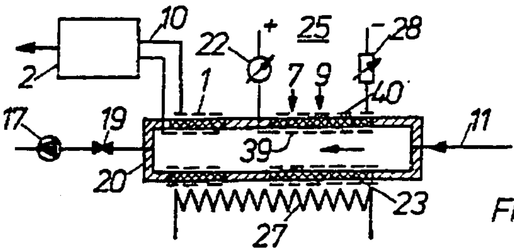

Fig. 3

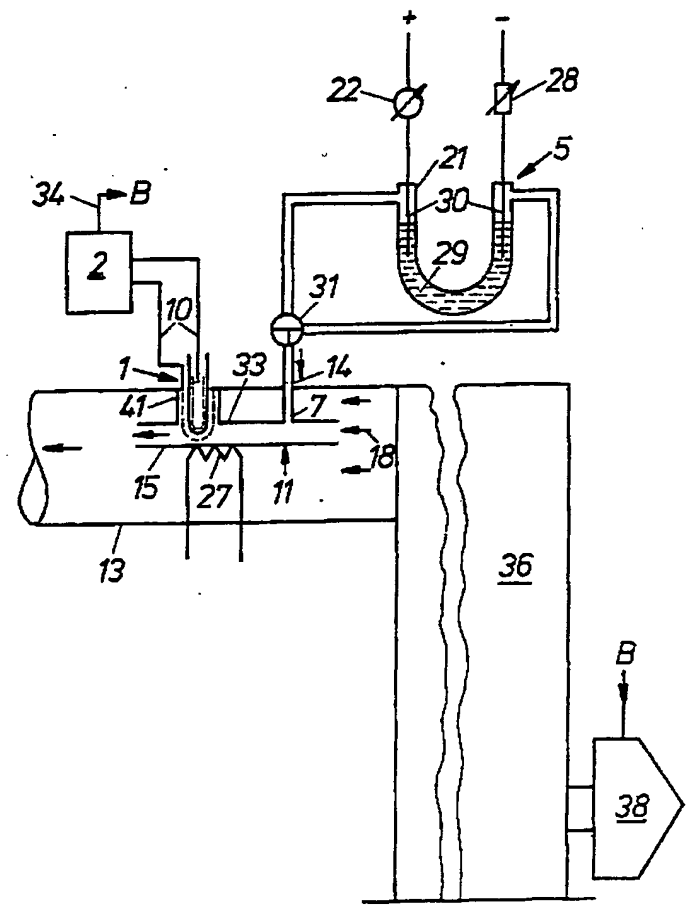

Fig. 4